Input-Output and Hybrid LCA (Subject Editor: Sangwon Suh)

A Regional Version of a US Economic Input-Output Life-Cycle Assessment Model

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Abstract

Background, Aims and Scope. Life cycle assessment models typically use product-specific, plant-level or national aggregate data. However, many decisions by regional policy makers would be better informed by local or regional aggregate data. This research is intended to construct and apply a regional US economic input-output analysis-based life cycle assessment (REIO-LCA) model based upon publicly available datasets. The model uses Gross State Product (GSP) estimates to calculate regional economic multipliers and then link them to regional electricity and fuel use, and air emission factors. Target audiences are governmental decision makers, industry experts and researchers concerned with the regional economic and environmental effects of public and private decisions.

Methods. A regional version of the existing US EIO-LCA model was developed using regional economic multipliers and state environmental data. The national model is based on the US 491 by 491economic input-output model, and uses sectoral energy consumption and emission factors to approximate the environmental effects of production and services. The proportion of the regional value added (Gross State Product) to the national value added for each sector was used to develop economic multipliers to allocate the output of industries to individual states and multi-state regions. Inter-sectoral transaction matrices were constructed for eight regions. Regional environmental emission and resource use factors were formed based upon publicly available data of the US Environmental Protection Agency (EPA) and Department of Energy. The Toxics Release Inventory include facility location parameters, enabling the estimation of sectoral toxic emissions for the regions. The national electricity and fuel use, air pollutants (CO, NO_x, PM_{10}, SO_2 and VOC) and greenhouse gas emissions used by the EIO-LCA model were proportioned based upon state totals for each sector.

Results. A regional economic input-output model was created for US regions, and sectoral energy use and environmental emission factors were estimated for Pennsylvania, the Far West (Alaska, California, Hawaii, Nevada, Oregon and Washington) and the Mideast (Delaware, District of Columbia, Maryland, New Jersey, New York and Pennsylvania) economic areas. The use of the framework for regional IO-LCA model is demonstrated through two case studies.

Discussion. As a validation exercise, the regional outputs of petroleum refineries were calculated using the regional input-output matrices and the outcomes were compared to the Energy Information Administration's (EIA) Petroleum State Profile data. The model results show that approximately 70% of the total national sectoral production takes place in three regions, i.e., South West, South East and Far West, which corresponds with the EIA statistics. The REIO-LCA model constructed for the Far West is used to conduct a second case study estimating the annual toxic air emissions of power plants in the region in 2003. The results are evaluated by comparison to data provided by the US EPA. The estimated pollutions do not differ significantly from those presented in the Toxics Release Inventory reports.

Conclusions. The usefulness of IO LCA models can be improved through the incorporation of local economic and environmental characteristics. Wiht the lack of US regional sectoral data, the allocation of national industrial production to regions can provide a framework to create smaller scale IO models. The results of case studies support the assumption that the GSP multipliers may be used to allocate the sectoral production to the regions, and show that the framework IO LCA model provides a reasonable approximation of supply chain economic activities and environmental effects caused by production and services.

Recommendations and Perspectives. The quality of data, e.g., age and level of aggregation, and the assumed linearity between sectoral outputs and environmental emissions represent the main sources of uncertainty in the model. The results show that the GSP estimates are appropriate to construct a framework for a regional economic input-output and environmental assessment model. However, further research is recommended to construct more specific state-level input-output matrices incorporating interstate commodity flows, and state environmental factors in order to mitigate the parameter uncertainties. Further, the model might be improved by updating it regularly, as more recent data become available.

Keywords: Electricity production; environmental emissions; gross state product; input-output LCA; refineries; regional economic input-output model

Introduction

Life-cycle assessment (LCA) became a widely used tool in the last decade to estimate environmental effects of the entire life cycle of products and services [1–3]. The accuracy and level of aggregation of data are essential for credible LCA. Process-based LCA studies have used mostly product-specific and plant-level data [4]. Economic input-output analysis-based LCA (EIO-LCA) has used national average data [5–7]. While both process LCA and EIO-LCA have been important decision-making tools, neither of them has been able to perform regional and state level analyses efficiently. We wish to develop a model that will indicate US regional economic and environmental effects from the production of goods and services. In turn, the regional model can be used to complement local, process based or national analyses.

This paper presents a regional US LCA model, Regional Economic Input-Output Analysis-based Life-cycle Assessment (REIO-LCA) that would enable regional (multi-state in the US) and state- level analyses. Such a model could be used for a variety of applications. It allows decision-makers to estimate both the economic and the environmental implications of changes in a regional economy, such as moving production of a sector into the region. For example, the supply chain electricity and fuel use, and consequently the emissions associated with production within and outside of the region may be estimated. Current regional models are focused on calculating the employment and output implications of a major addition to, or deletion from, the economy of a state. The REIO-LCA model will quantify regional environmental effects.

Several commercially available US regional economic modeling software tools exist, including the Regional Input-Output Modeling System (RIMS II), Regional Economic Models Inc. (REMI), and Impact Analysis for Planning (IMPLAN) [8–10]. They differ mainly in the way they calculate regional economic multipliers [11], which are factors indicating the proportion of economic activity in a region relative to the national total. Economic multipliers are needed since the economic census only reports national inter-sectoral transactions. RIMS II [8] is derived from two data sources: the national I-O table, which shows the inter-industry relations of 491 US sectors, and location quotients, which are used to adjust the national I-O table to show the industrial structure and trading patterns of any region composed of one or more counties [12,13]. REMI is a computing, forecasting and simulation model for a region that assesses the economic and demographic impacts that a policy, project or new industry may cause in a local economy [14–16]. IMPLAN measures the economic impact of new projects in a region and includes the direct and indirect effects. IMPLAN develops an I-O model at the local level based on US national I-O accounts and regional purchase coefficients [10]. Since these models are restricted to economic data, the prediction of regional environmental effects requires additional effort from the users. Once the regional economic impacts are estimated, the user has to find appropriate resource use and emission data that can be related to the model results. This process significantly increases the time required and consequently the costs of the assessment. Our regional EIO-LCA model is based upon publicly available data and incorporates regional environmental data to enable regional emission estimation.

Regional input-output models for environmental life cycle assessment have also been developed and investigated in other parts of the world [7,17]. In particular, inter-regional transactions models have been investigated [18]. These efforts depend crucially upon the level of detail of economic and environmental activity provided at the regional scale. Efforts such as the European NAMEA for economic and environmental accounting are helpful in particular regions and could be usefully extended globally [19]. In this paper, we restrict attention to data sources available in the US.

1 Methods

Table 1 summarizes the various data sets, availability and use in the REIO-LCA model. Several of the data sets required allocations and aggregations to correspond to the 491 economic input-output sectors defined by the US Bureau of Economic Analysis. In the discussion following, the various manipulations are described.

1.1 Regional Economic Input-Output Model

Similar to the existing commercial regional models described above, our US regional economic input-output model is developed by constructing a table of regional inter-sectoral transactions based upon the national totals and regional proportional economic multipliers. With a regional transactions table, the regional requirements table can be estimated by dividing each column by the regional output (as is done to develop the national EIO-LCA model). However, we use publicly available Gross State Product (GSP) data to create regional economic multipliers to enable a publicly available regional model. As noted above, regional sectoral outputs and inter-sector transactions are not reported by the US Census Bureau.

Using definitions and notation from [5], a regional 491×491 total requirements matrix was created by modifying the national inter-industry transaction matrix for 1997 by using economic multipliers indicating the distribution of sectoral production to regions. GSP estimates, defined as "the value added in production by the labor and property located in a

Table 1: Summary of data types used, availability and model use

Data Type	Availability	Model Use
National economics transactions table	US 491x491 sector benchmark model for 1997 is available [22]	Initial factors for regional transactions table
Gross state product multipliers	Reported for 63 sectors by region and state for 1997 [20]	Allocated to 491 sectors and used as multipliers on national table for the regional model
Energy, fuel and greenhouse gas emissions	National totals by type of energy, fuel and greenhouse gas emissions [29]	Allocated by regional fractions of output and divided by regional sector outputs
Conventional air emissions	Emissions by state by SIC category [25,27]	Converted to regional IO sector emissions and divided by sector output
Toxics air emissions	Emissions by facility by SIC category [26]	Aggregated to regions, converted to regional IO sector emissions and divided by sector output

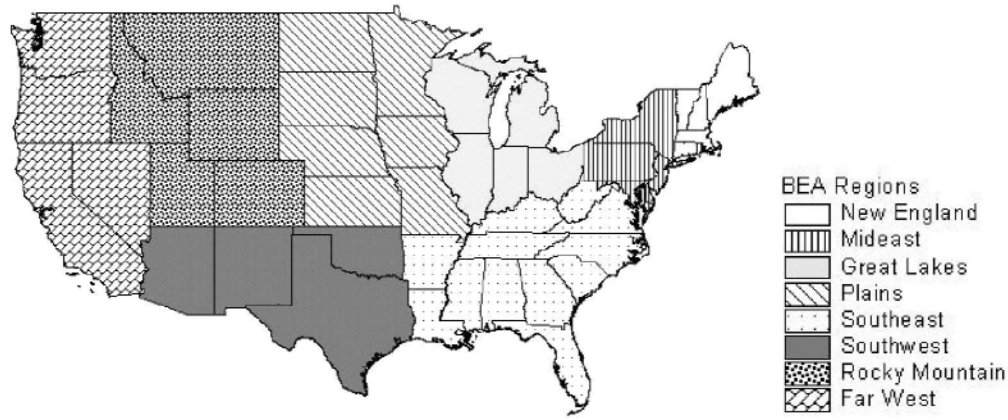

Fig. 1: Location of US Bureau of Economic Analysis regions

state" [20] were chosen to form regional economic multipliers. GSP estimates are available for all US states, the District of Columbia, eight regions defined by the US Bureau of Economic Analysis (BEA) (**Fig. 1**), and for 63 two- and three-digit North American Industry Classification System (NAICS)-based aggregated US industries in millions of current dollars and in millions of 2000 dollars. The value added for any industry k (V_k) is the difference between its total sectoral output (X_k) and the total cost of intermediate purchases (purchases from other sectors, I_k) [20]:

$$GSP_k = V_k = X_k - I_k \tag{1}$$

To use the GSP data as a basis for a regional model, it was assumed that the proportion of annual output of sector k occurring in region R could be approximated by the ratio of value added by industry k in region R to the total national value added by sector k:

$$\frac{X_k^R}{X_k^{US}} \approx \frac{V_k^R}{V_k^{US}} = \frac{GSP_k^R}{GSP_k^{US}} \tag{2}$$

where

X_k^R= total annual output of industry k occurring in region R

$X_k^{US} = \sum_R X_j^R$ = total annual national output of industry k

V_k^R = total value added for industry k in region R

$V_k^{US} = \sum_R V_k^R$ = total national value added for industry k

GSP_k^R = GSP estimate for industry k in region R

$GSP_k^{US} = \sum_R GSP_k^R$ = BEA's GSP estimate for industry k for the US

$\frac{GSP_k^R}{GSP_k^{US}}$ = regional multiplier for industry k in region R

In effect, we are assuming a proportional allocation of output using the regional value added for a sector or group of sectors, where the group reflects the more aggregate reports of GSP relative to the national input-output table. We apply this assumption to each row of the national input-output transactions table.

The reasonableness of the GSP allocation assumption can be checked by regression analysis on the national-level value added and output in each sector. The correlation between the 491 input-output industries' national annual outputs and the value added rates for 1997 was examined [23]. The regression analysis (**Fig. 2**) showed that the sector output values might be predicted with good confidence (R^2 = 90%) using the sectoral value added rates. Thus, the regional and national sectoral GSP estimates were chosen to create economic multipliers since regional and national value added estimates and national sectoral outputs are available.

The GSP estimates for 63 sectors had to be allocated to the 491 national I-O industries to create regional multipliers. There is no direct relationship defined between the GSP and the national I-O industries, but information was available about industries (defined by their NAICS) included in GSP estimates of sectors [17]. The Survey of Current Business 2002 includes information about NAICS sectors related to I-O industries [19]. Based on the survey, a bridge was created mapping the NAICS sectors to all but two I-O industries: I-O number S00700 Inventory valuation adjustment, and I-O number S00800 Owner-occupied dwellings [20]. Based on this, multipliers were calculated for each BEA region.

The national inter-industry transaction matrix was modified using the regional multipliers to form total requirement coefficient matrices for all eight regions. The national transaction matrix was derived from the direct requirements matrix (**A**) and total industry outputs for 1997 (X_j^{US}) as:

$$X_{ij}^{US} = a_{ij} * X_j^{US} \tag{3}$$

where

X_{ij}^{US} = dollar input from industry i required by sector j to produce its total national annual output

a_{ij} = direct requirement coefficient, \$ input from industry i required by sector j to produce \$1 output [22]

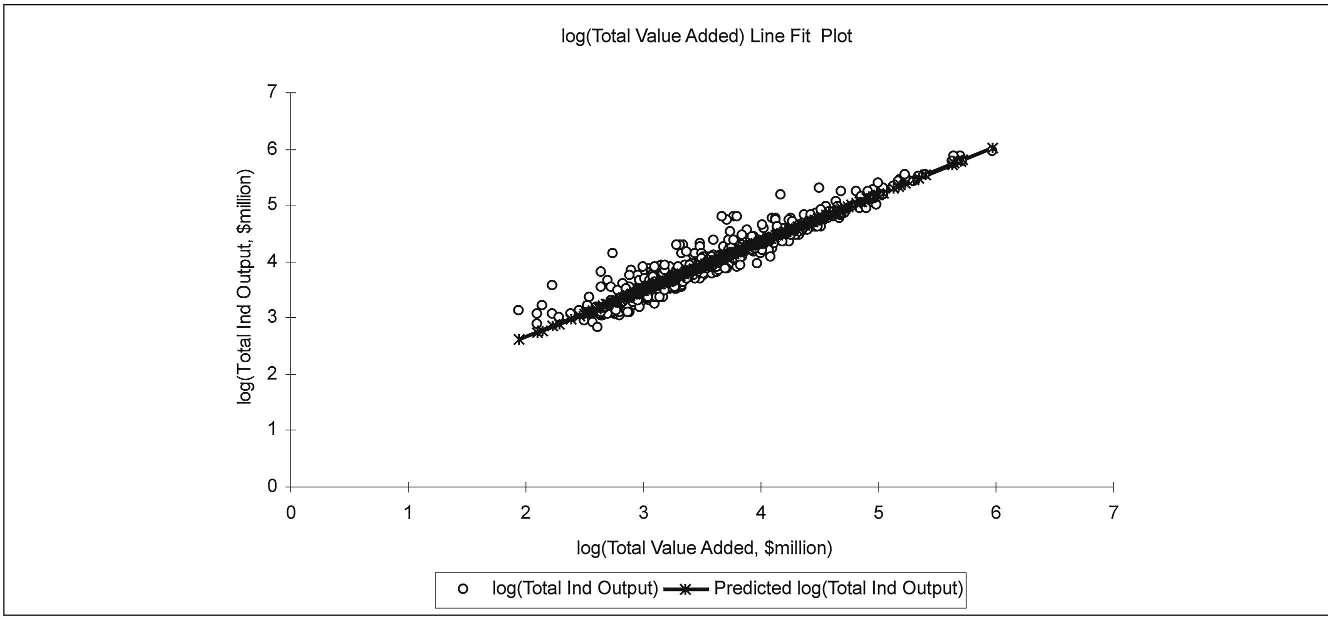

Fig. 2: Regression analysis of national industry outputs and value added

$X_j^{US} = \sum_{i=1}^{491} X_{ij}^{US} + GSP_j^{US}$ = total annual input for industry j which is equal to the total national output of industry j [22]

The regional transaction matrix entries (X_{ij}^R) were calculated on the basis of proportional production in each row of the transactions matrix (Eq. 2):

$$X_{ij}^R = X_{ij}^{US} * \frac{GSP_i^R}{GSP_i^{US}} \quad (4)$$

where

X_{ij}^R = dollar input from industry i required by sector j to produce its total annual output (X_j^R) in region R

X_{ij}^{US} = dollar input from industry i required by sector j to produce its total national annual output (X_j^{US})

$\frac{GSP_i^R}{GSP_i^{US}}$ = regional multiplier for industry i in region R

was estimated using the definition of total sectoral output:

$$X_j^R = \sum_{i=1}^{491} X_{ij}^R + GSP_j^R \quad (5)$$

The regional direct requirement coefficients (a_{ij}^R) were calculated as:

$$a_{ij}^R = \frac{X_{ij}^R}{X_j^R} \quad (6)$$

The regional **A** matrix ($\mathbf{A}^R$) can be used to estimate vectors of total outputs ($\mathbf{x}_\mathbf{y}^\mathbf{R}$) to provide **y** final demands in region R:

$$\mathbf{x}_\mathrm{y}^\mathrm{R} = \left[\mathbf{I} - \mathbf{A}^\mathrm{R}\right]^{-1} * \mathbf{y} \quad (7)$$

where **I** is the identity matrix [24]. Note that our regional model derivation focused upon modifying the transactions table to reflect production within the region. To form a complete input-output model, consideration for imports into final demand could be added but this is not necessary for our purpose of estimating impacts of regional production.

1.2 Regional Environmental Vectors

Our objective in developing environmental vectors was to estimate environmental emissions and resource inputs for unit operations defined as $1 of output of I-O sectors for all eight regions. We have estimated electricity and fuel use, emissions of some air pollutants (CO, NO_x, PM_{10}, SO_2 and VOC), toxic air emissions, and greenhouse gas (GHG) emissions.

Air emissions are reported by facilities to the US Environmental Protection Agency (EPA) [25, 26]. All databases are publicly available on the EPA's website and include the location of reporting facilities. The bridge between SIC, NAICS and I-O 1997 industries was used to do similar estimations to those described above to obtain the sectoral toxic release factors. Since the AirData report is restricted to point sources, the National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data for 2002 [27] were also used to estimate the air emission factors for the input-output industries. The regional emissions were divided by the regional sectoral outputs estimated using the regional economic model presented above to create the emission factors in metric tons per $1 of output.

Since there are no detailed state level electricity, fuel use, and greenhouse gas emission data available for the I-O industries, regional sectoral multipliers were used to allocate

the respective national data to the regions. The multipliers were created from regional total annual emission and sectoral output data.

2 Uncertainties in the Model

Similarly to the national input-output based models, the main sources of uncertainty related to REIO-LCA are the quality of data used to develop the model, the assumed linearity between sectoral outputs and environmental burdens, and the method applied to allocate aggregated data to the IO 1997 industries [2,30,31]. Although the regional GSP values vary year-by-year, the sectoral fractions of national GSP occurring in different regions are similar between 1992 and 2002. Older environmental data (e.g., some of the state GHG inventories used to estimate regional emission multipliers are from 1990) incorporate larger uncertainties since sectoral emissions might be changing. The air emission reports used in the model are from 1999 and 2002, and the TRI data are from 2003. Thus, the model may be improved by updating it using newer economic and environmental data, albeit the 2002 benchmark input-output accounts will not be published until 2007. Presumably, the model overestimates air emissions as well as toxic releases since both have decreased over time [32,33]. In contrast, energy consumption and GHG emissions have increased year-by-year, e.g., the total US GHG emissions increased by 13% between 1990 and 2003 [34,35]. However, the total national gross domestic product has increased by 46% during the same period [34], thus the actual sectoral GHG emission factor is lower than that used by the REIO-LCA model.

Both the national and regional models incorporate uncertainties due to the allocation methods used to estimate the sectoral environmental factors. The international standards ISO 14040 and 14041 provide requirements regarding the allocation methods in LCA [37,38]. Nevertheless, the compliance with these and other requirements of the standards is challenging when conducting LCA study using an I-O LCA model since the nomenclature is specified for process LCA. However, defining the unit process, which is the smallest portion of the product system data are collected for, as the production of $1 of sector output enables the interpretation of basic requirements included in the standards. The ISO 14040 standard defines allocation as "partitioning the input or output flows of a unit process to the product system under study." All input categories used in the EIO-LCA models are estimated for $1 of sector output. Further, the standard states that if the system involves multiple products the inputs and outputs should be allocated to the different products. This requirement is not applicable for the EIO-LCA models. The description of the national model, which is available on the eiolca.net website, satisfies the last requirement of the standard, i.e., the allocation method shall be documented.

Other sources of uncertainty include lack of data, level of aggregation and the incorporation of imported commodities in the input-output accounts. For example, the TRI has some limitations [26]. It provides information on releases, disposal and management of approximately 650 toxic substances, but not on exposures or potential impacts on population and the environment. It does not cover all sources of toxic releases since facilities below thresholds and industries, e.g., construction selected industries and service sectors, do not have to report. The number of chemicals is limited, too. In addition, facilities may choose to base their TRI data on estimations or monitoring since the program does not require monitoring of releases. Furthermore, the State Energy Data prepared by the Energy Information Administration has constraints due to inadequate data sources [34]. The estimates for 63 GSP industries had to be allocated to the 491 I-O sectors to create regional multipliers [23]. The bridge between the GSP and IO 1997 sectors also incorporates uncertainty. One-to-many relationships occur between industries several times in the bridge. Hybrid LCA, the combination of process-based and EIO-LCA provides a solution for this problem [3].

3 Results

The national sectoral production of each benchmark industry was allocated to states, and input-output matrices were formed for all eight multi-state regions, California and Pennsylvania. Impacts from purchases of goods and services from all 491 economic sectors can be analyzed with the model, including supply chain impacts. We illustrate these estimations by applying the regional input-output model for the petroleum refinery industry. The BEA defines one GSP sector for petroleum production: 31 Petroleum and coal products manufacturing. This sector incorporates the following five NAICS industries [20]: 324110 Petroleum refineries, 324121 Asphalt paving mixture and block manufacturing, 324122 Asphalt shingle and coating materials manufacturing, 324191 Petroleum lubricating oil and grease manufacturing, and 324199 All other petroleum and coal products manufacturing. Since each sector above is mapped one-to-one to an input-output industry, the ratio of national sectoral outputs to the sum of the five outputs were used to allocate the regional GSP estimates to the NAICS industries. The NAICS sector 'Petroleum refineries' corresponds to the benchmark I-O industry 'Petroleum refineries.' **Table 2** presents the GSP estimates and regional multipliers for the sector.

The GSP multipliers indicate the proportions of national annual production of petroleum refineries occurring in the regions, e.g., the contribution of the Far West region to the total national output is 28%.

The use of environmental emission factors is shown through the estimation of annual toxic releases of power plants in the Far West economic region. The region incorporates the following states [17]: Alaska, California, Hawaii, Nevada, Oregon and Washington. The objective of the case study is to calculate the amount of toxic air emissions from power plants in the region in 2003 using the regional EIO-LCA model and, for comparison, emissions from the national model. 392.4 million MWh of electricity were generated in the Far West region in 2003 [34]. The regional average producer price was approximated using state-level retail prices

Table 2: Example of GSP estimates and multipliers for the eight regions and the U.S for Petroleum Refineries

Region	GSP 31, Petroleum and coal products manufacturing [$ million]	NAICS 324110, Petroleum refineries [$ million]	I-O 324110, Petroleum refineries [$ million]	GSP multiplier, GSP_j^R/GSP_j^{US} [%]	Estimated total sectoral output, [$ billion]
Far West	7,700	6,900	6,900	28.27	44
Great Lakes	3,000	2,700	2,700	11.22	17
Mideast	3,000	2,700	2,700	11.04	17
New England	210	180	180	0.76	1.2
Plains	910	810	810	3.34	5.2
Rocky Mountain	510	460	460	1.89	2.9
Southeast	4,600	4,100	4,100	16.97	26
Southwest	7,200	6,400	6,400	26.52	41
U.S.	27,000	24,000	24,000	100.00	160

because of lack of data [38]. The desired final demand (y_{221100}^{FW}) in the Far West region for the power generation and supply sector (I-O number 221100), was calculated by multiplying the amount of electricity generated by the estimated average price of 8¢/kWh including cost of generation, transmission, and distribution. The vector of total regional sectoral outputs needed to produce $y_{221100}^{FW} = \$31{,}392$ million, and the toxic air emissions associated with it were estimated using the 491×491 GSP-based REIO-LCA model created for the Far West region. **Table 3a** and **3b** present the ten largest sectoral outputs calculated using the regional and national EIO-LCA models, respectively.

The largest contributors were the power generation and supply (61%), oil and gas extraction (6%), and pipeline transportation (4%) sectors in the region. The quantity of emitted toxic substances was estimated by multiplying the sectoral TRI emission factors for the region with the supply chain

Table 3a: The ten largest supply chain sector outputs required to generate the annual amount of electricity in the Far West region in 2003, estimated using the **regiona**l model

IO 1997	Sector name	Sector output, $ million
221100	Power generation and supply	31,390
211000	Oil and gas extraction	2,900
486000	Pipeline transportation	1,800
324110	Petroleum refineries	940
531000	Real estate	830
541100	Legal services	820
420000	Wholesale trade	790
230340	Other maintenance and repair construction	630
482000	Rail transportation	460
52A000	Monetary authorities and depository credit intermediation	440
Total for all 491 sectors		**51,000**

Table 3b: The ten largest supply chain sector outputs required to generate the annual amount of electricity in the Far West region in 2003, estimated using the **national** model

IO 1997	Sector name	Sector output, $ million
221100	Power generation and supply	32,000
211000	Oil and gas extraction	3,100
212100	Coal mining	2,500
486000	Pipeline transportation	1,100
482000	Rail transportation	960
420000	Wholesale trade	790
533000	Lessors of nonfinancial intangible assets	730
324110	Petroleum refineries	680
541100	Legal services	630
Total for all 491 sectors		**54,800**

Table 4: Comparison of estimated and reported amounts of top ten toxic chemicals emitted by electric utilities in the Far West region in 2003

CAS number	Chemical name	Estimated toxic air emission, [mt]	Reported air emission, [mt]	Ratio of estimated and reported
007664939	Sulfuric acid	810	780	1.04
007647010	Hydrochloric acid	410	410	1.00
007664393	Hydrogen fluoride	180	180	1.00
007664417	Ammonia	130	140	0.93
No CAS number	Nickel compounds	24	24	1.00
No CAS number	Barium compounds	14	13	1.08
007440393	Barium	10	10	1.00
007782414	Fluorine	9.8	9.5	1.03
007439965	Manganese	9.7	9.4	1.03
No CAS number	Diisocyanates	5.5	5.3	1.04

Table 5: Regional distillation capacities of petroleum refineries and share estimates for 2004

Region	EIA regional capacity [10^6 bbl per day]	EIA regional share [%]	Estimated regional output/U.S. output [%]	Estimated output/ EIA share
Far West	3.11	18.54	28.27	1.52
Great Lakes	1.95	11.65	11.22	0.96
Mideast	1.58	9.43	11.04	1.17
New England	0	0	0.76	NA
Plains	0.69	4.11	3.34	0.81
Rocky Mountain	0.58	3.47	1.89	0.54
Southeast	3.81	22.73	16.97	0.75
Southwest	5.04	30.07	26.52	0.88
U.S.	16.76	100	100.00	1.00

sector outputs presented in the previous example. The ten largest emissions of the power generation and supply industry, representing 99% of the total toxic emissions of electric utilities, are shown in **Table 4**.

The toxic air emissions of electric utilities in the Far West region, estimated using the national and regional models, were compared to the state TRI reports generated by the TRI Explorer for electric utilities [45]. The national model estimates similar total economic effects, although in that case the third largest supplier is coal mining instead of pipeline transportation due to the difference between the regional and the national electricity generation mix [46]. Table 3 demonstrates the outcome of the comparison.

The ratio of estimated and reported toxic releases shows that the regional EIO-LCA model may be used with good confidence to approximate pollution discharges as the largest difference between the compared amounts is 8%.

4 Discussion

The estimated regional outputs of petroleum refineries were evaluated by comparing them to the Energy Information Administration's (EIA) Petroleum State Profile data for 2004. This is a rational method for evaluation of the model outcomes since the average utilization rate of operating capacity of the US petroleum refineries was approximately 90% in 2004. Further, there was no significant petroleum refinery built in the US during the last 30 years, which resulted in less than 10% increase of the total national operating capacity from 1997 to 2004 [43]. The regional capacity values of petroleum refineries were calculated by adding up state data for the regions. They were then divided by the total national operating capacity, 16.76 million barrels per calendar day for 2004 to obtain the regional share estimates [43]. **Table 5** presents the results of calculations from the EIA data as compared to the estimates from Table 2.

The largest differences between the EIA and estimated regional shares appeared in the Far West (52%) and the Rocky Mountain (46%) regions.

5 Conclusions

A US regional IO-LCA model was formed incorporating publicly available US state economic and environmental data. The regional total requirements matrix has been created for all eight BEA regions and environmental vectors have been estimated for California, Pennsylvania, the Far West and the Mideast. The applications of the model show that the GSP estimates may be used to construct regional economic input-output matrices. As expected, there were no major differences between economic activities generated by the same final demand on the national and regional levels since

the REIO-LCA model was created assuming that the entire supply chain of a product was located in the multi-state region. Application of the same method for a single state would be biased as there are industries in each state with zero GSP estimates, and the interstate flow of commodities also implies significant use of imported goods in state production.

6 Recommendations and Perspectives

Regional models are of interest due to the importance of local impacts for many decision makers. However, the lack of regional data on production and environmental emissions hamper regional analyses. We have outlined an approach that provides estimates of regional impacts that can be compared with national models or with process based life cycle assessment methods. Definitive regional models will require more extensive local data.

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